

Wastewater Phosphorus Removal and Environmental Life Cycle Assessment

Idaho Water Reuse Conference

May 24, 2011

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Presentation Outline

- Phosphorus and the environment
- Phosphorus forms and analytical methods
- Methods for removing phosphorus from wastewater
 - Including some relevant observations from my lab group's research
- Comparing phosphorus removal methods
 - Using Environmental Life Cycle Analysis
- Conclusions and recommendations



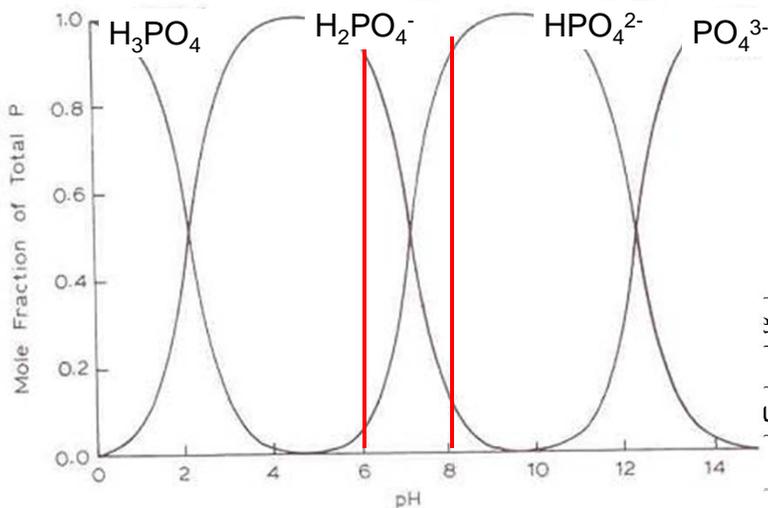
Phosphorus and the Environment

- Principle concern = excess algae growth
- Leads to depletion of dissolved oxygen and advanced eutrophication
 - Phosphorus is most commonly the “limiting” nutrient for algae growth
- Effluent limits becoming increasingly stringent
 - Potentially as low as 0.01 mg/L
- We should apply the Best Available Technology and consider the local water environment (but not the expense of the global environment)



Forms of Phosphorus in Wastewater

- Soluble reactive P (i.e., PO_4^{3-})



Effect of pH on the distribution of orthophosphate ions in solution.

ulate



Phosphorus Measurement



- WERF has some nice research on this subject
- Current methods center on measuring SRP
 - Ascorbic acid method (colorimetric) most common
 - e.g., Standard Method 4500; EPA 365.1-.4
 - Must acid hydrolyze particulate P to SRP
 - Accuracy & precision = real concern
 - e.g., Hach Phosver3.....detection limit=0.02 mgP/L
 - Shimadzu UV/vis spec meets this specification
 - Standard “bench-top” units may be insufficient
 - No real nexus between proposed numeric criteria and the realities of method accuracy/precision
 - **Arguably proposing P limits we cannot accurately and precisely measure**

Removing Phosphorus from Wastewater

- Chemically
- Biologically (BPR)



Chemical Phosphorus Removal

- Coagulate using metal salts (Al or Fe-based)
 - Principally targets soluble reactive P
 - Chemical dose required:
 - Generally follows stoichiometry at $P > 1 \text{ mg/L}$
 - Molar Me:P ratio $\sim 1-3$
 - Molar ratio increases substantially as effluent requirements become more stringent
 - Molar Me:P ratio $\gg \gg 3$
 - Rapid, instantaneous mixing is key!
 - $G = 300-400 \text{ s}^{-1}$; 1-20 s detention time
 - Flocculation recommended
 - Flocs removed via filtration

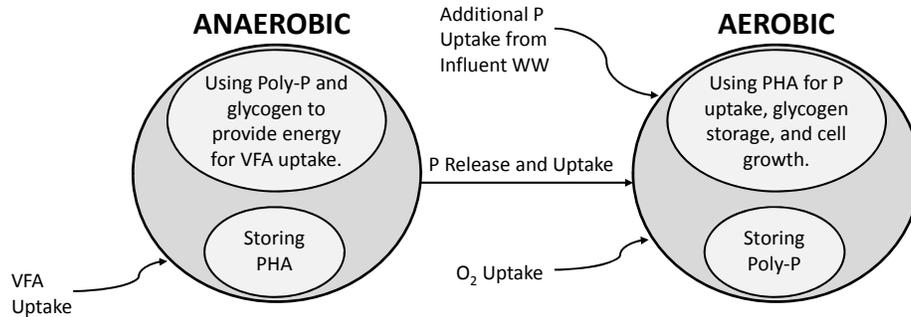


Chemical Phosphorus Removal

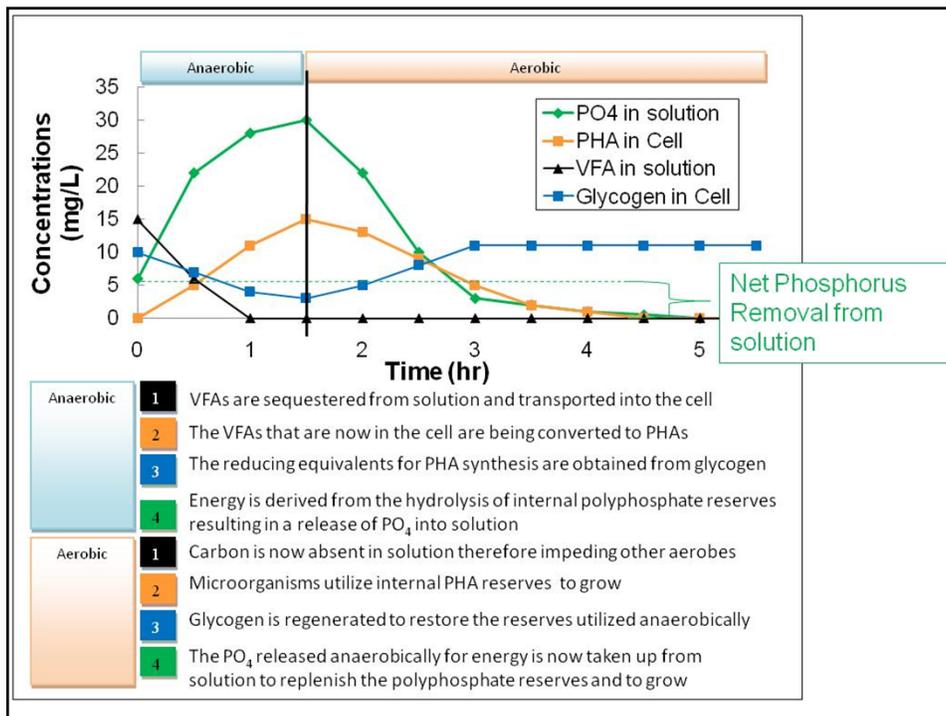
- Can add metal salts @ multiple locations
- Polymer addition can enhance floc formation
- Optimal chemical dose....jar testing
 - But, at very low P, flocs can be very difficult to see



Biological Phosphorus Removal (BPR)



- Relies on the presence of polyphosphate accumulating organisms (PAOs)
 - Select for PAOs by anaerobic/aerobic cycling
 - PAO fraction can vary as a % of total biomass



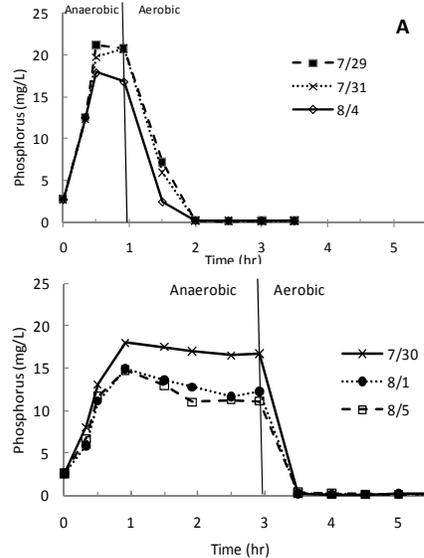
BPR Observations – Coats’ lab....

■ Candidatus *Accumulibacter phosphatis*

- The “model” PAO
- 1-45% of population
 - Stable BPR regardless of population variability

■ Anaerobic HRT

- **Key = max P release with VFA depletion**
- Too long...concern for secondary P release?
 - We have observed no such problem
- Longer HRT = faster AE P removal?



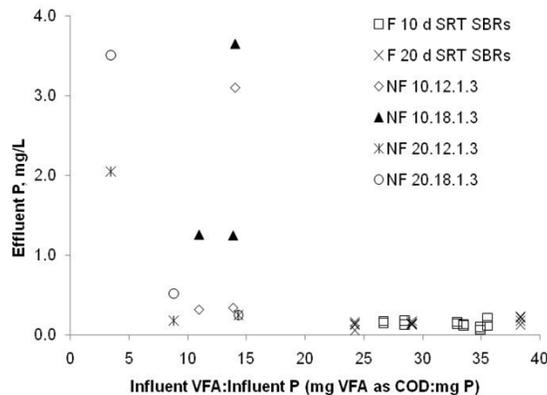
BPR Observations – Coats’ lab....

■ Effects of SRT

- Longer = better performance
 - Tested 10-20 day SRTs
- As SRT increases, need for VFA augmentation seems to decrease

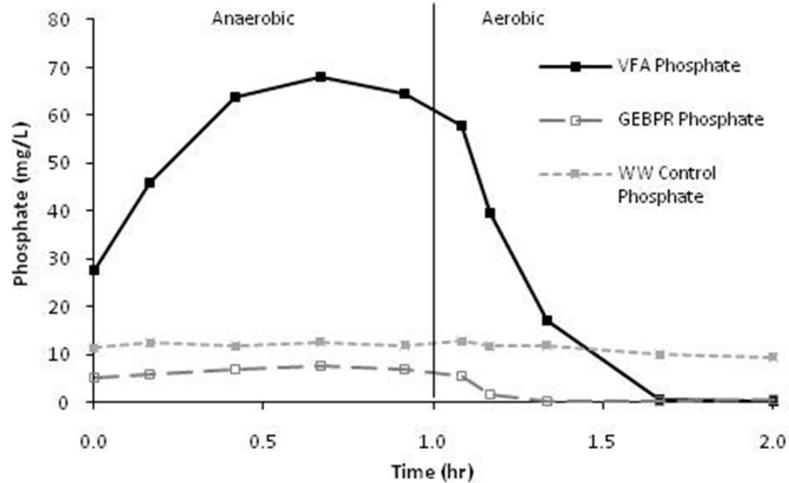
■ VFA addition

- > 15 mg VFA (as COD) per mg influent P yields consistently stable BPR

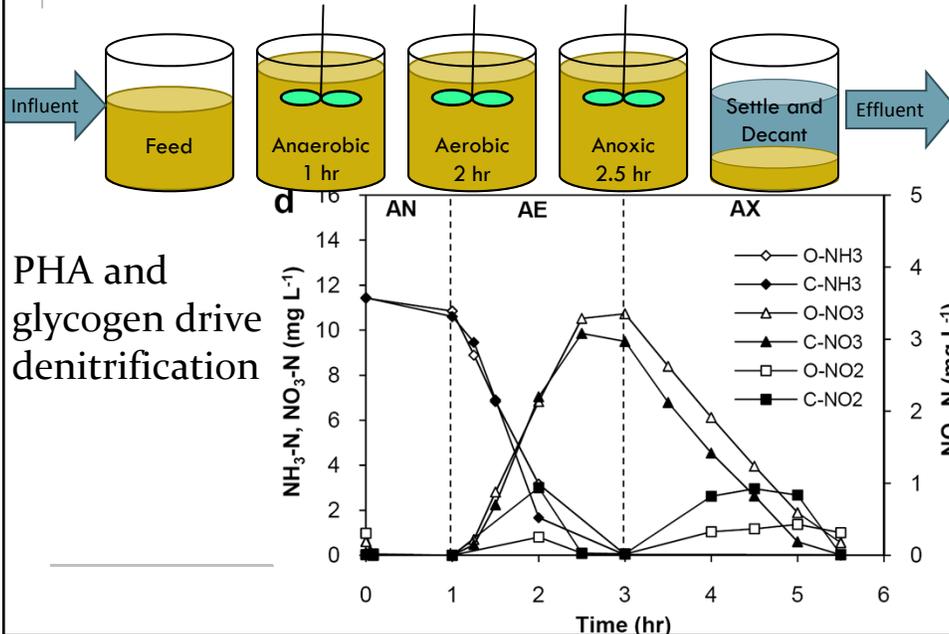


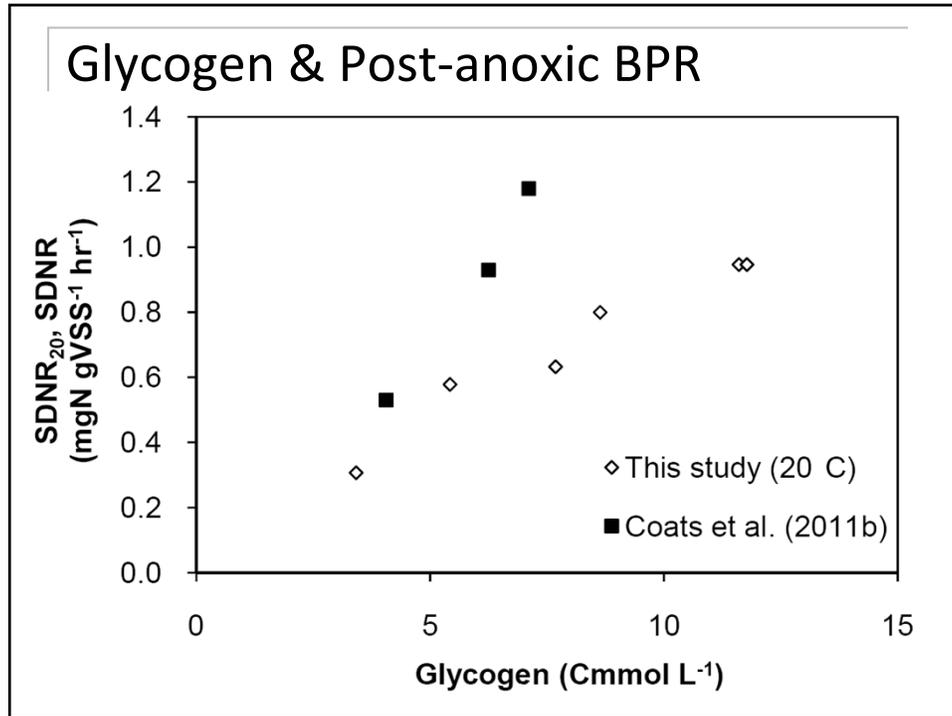
BPR Observations – Coats' lab....

- Use crude glycerol in lieu of VFAs?
 - Is a byproduct of biodiesel production
 - Contains methanol and glycerol



New Configuration: Post Anoxic BPR





Chemical P Removal vs. BPR

So which one is best?
How could we make such a
determination?



Environmental Life Cycle Assessment

- Analytical tool for developing metrics with which to compare/contrast processes
- Some environmental impacts assessed....
 - Eutrophication
 - Global climate change
 - Human health impacts
 - Acid rain
- Model inputs = energy & raw materials used
- Model outputs = waste or emissions
- One more metric to assess alternatives



“Optimal” level of Treatment?

- Foley et al. (2010) – Water Research (BioWin-based)
 - GHG emissions up sharply from TN/TP 10/5 to 5/5 (mg)
 - Resource consumption up sharply from TN/TP 5/5 to 5/1 (mg)
- Lundie et al. (2004) – Environ Science & Technol
 - O&M impacts >>> impacts associated with construction
- Lundin et al. (2000) – Environ Science & Technol
 - Centralized WWTP = less unit energy decentralized WWTPs
 - But, centralized = higher fossil resources & CO₂ emissions
- Hospido et al. (2008) – Int Journal LCA
 - Lower effluent N/P = reduced eutrophication potential, but at a global environmental cost (e.g., GHG emissions; ozone depletion)
- No “one size fits all” assessment....case-by-case assessment



Developing an ELCA

- Need to establish a functional unit
 - Our phosphorus study.....10 MG of reclaimed water
- System boundary
 - Evaluate all process elements within boundary
 - Our study....
 - Secondary and tertiary treatment processes
 - Alum production
 - Chemical sludge production
 - Energy production
 - Geographic location
 - Important for the energy component



ELCA Model & Assumptions

- Model = T.R.A.C.I. (U.S. EPA)
 - Based on U.S. environmental regulations
- Emissions applied to each applicable category
 - e.g., NO_x applied to eutrophication (air), smog (air), and acidification (air)
- Model based on mid-point impact
 - e.g., “potential” to cause global climate change



Our Scenarios

- Scenario #1 – designed using BioWin™
 - Achieve effluent = 0.5 mgP/L
 - Strictly BPR (with fermenter)
vs.
 - Pre-anoxic denitrification coupled with chemical P removal
- Scenario #2 – data from full-scale WWTPs
 - Achieve effluent = 0.1 mgP/L
 - Pre-anoxic denitrification coupled with chem P
vs.
 - BPR followed by chem P removal



Data Quality & Simplifications

- CO₂ associated with biological activity was excluded as being “biogenic”
- Common processes (e.g., RAS, MLR, preliminary treatment) were excluded
- Aluminum sulfate manufacturing
 - No detailed data on Alum mfring emissions
 - Therefore, alumina manufacturing used as a surrogate



Scenario #1 (0.5 mgP/L) Emissions			
Activity	Emission	Scenario #1 (kg per 37,854 m³ of treated wastewater)	
		#1A-Chemical	#1B-BPR
Energy (Total)	NO _x	5.18	6.02
	SO ₂	4.04	4.69
	CO ₂	2,940.84	3,414.15
Alum Used	kg	765	--
Alum Transport to WWTF	CO ₂	519.1	--
Chemical Sludge Transport	sludge (wet)	1,346	--
	CO ₂	16	--
TOTALS	NO _x	5.29	6.02
	SO _x	0.07	0.00
	SO ₂	4.04	4.69
	CO ₂	3,798.94	3,609.15
	CO	0.06	0.00
	P	19.0	18.2
	N	230.05	247.5
	NH ₃	59.8	110.5

Scenario #2 (0.1 mgP/L) Emissions			
Activity	Emission	Scenario #2 (kg per 37,854 m³ of treated wastewater)	
		#2A-Chemical	#2B-BPR+Chemical
Energy (Total)	NO _x	5.91	6.17
	SO ₂	4.61	4.81
	CO ₂	3,350.92	3,502.30
Alum Used	kg	2,513	1,456
Alum Transport to WWTF	CO ₂	1,703.7	986.6
TOTALS	NO _x	6.28	6.38
	SO _x	0.22	0.13
	SO ₂	4.61	4.81
	CO ₂	5,622.62	4,870.9
	CO	0.20	0.12
	P	4.3	5.2
	N	--	--
	NH ₃	7.4	3.5

Scenario #1 ELCA		
Category	Scenario #1 (kg per 37,854 m³ of treated wastewater)	
	#1A-Chemical	#1B-BPR
Global Warming Air (CO ₂ -e)	3,798	3,609
Eutrophication Water (N-e)	460.8.1	505.5
Due to nitrogen	321.6	372.9
Due to phosphorus	138.2	132.6
Acidification Air (H ⁺ moles-e)	420.8	479.4
Smog Air (g NO _x /m)	6.6	7.5
Eutrophication Air (N-e)	0.23	0.27
HH Criteria Air (milli-DALYs)	0.06	0.07
HH Noncancer Water (toluene-e)	3.5	6.5

Scenario #2 ELCA		
Category	Scenario #2 (kg per 37,854 m³ of treated wastewater)	
	#2A (RC)- Chemical	#2B (DM)- BPR+Chemical
Global Warming Air (CO ₂ -e)	5,622	4,871
Eutrophication Water (N-e)	612.5	476
Due to nitrogen	581	438
Due to phosphorus	31.5	38
Acidification Air (H ⁺ moles-e)	470.5	491.7
Smog Air (g NO _x /m)	7.3	7.7
Eutrophication Air (N-e)	0.26	0.27
HH Criteria Air (milli-DALYs)	0.06	0.07
HH Noncancer Water (toluene-e)	0.26	0.21

Conclusions & Recommendations

- We need to removal P from wastewater
 - However – we need to assess locally & globally
 - Expand our metrics for process selection
- If at all possible use BPR as a first line of defense
 - Incorporate VFA augmentation
- Chemical P removal
 - “footprint” increases with higher alum dosing
 - Rapid and efficient mixing
 - Jar testing
 - Dose before BPR? Chemical dose can be reduced
 - Our preliminary research suggests that effluent concentration may be a function of influent concentration

Some References

- Nutrient Control Design Manual
 - EPA/600/R-10/100 (August 2010)
- Methods for Wastewater Characterization in Activated Sludge Modeling (WERF (2003))
- Significance of Design & Operational Variables in Chemical P Removal
 - Szabo et al., WER (2008)
- Water Environment Research Foundation
- My web site....
 - <http://www.webs1.uidaho.edu/ecoats/>



Thank you!

Questions?

